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SPECIFICATION

TITLE OF THE INVENTION

EXCITATION CONTROL DEVICE AND EXCITATION CONTROL METHOD

TECHNICAL FIELD

The present invention relates to an excitation control device and an excitation control method used for both the stabilization of voltage in an electric power system and the improvement of steady-state stability in the electric power system.

BACKGROUND ART

Fig. 1 is constitutional view of a conventional excitation control device. In Fig. 1, 1 indicates a synchronous machine. 2 indicates a transformer. 3 indicates a circuit breaker. 4 indicates a power transmission line. 5 indicates a power transmission bus line. 6 indicates a potential transformer (hereinafter, called PT) for detecting a voltage V_G of an output terminal of the synchronous machine 1. 7 indicates a current transformer (hereinafter, called CT) for detecting a reactive current I_Q output from the synchronous machine 1. 8 indicates a voltage setting device for setting a reference voltage V_{Gref} of the output terminal of the synchronous machine 1 according to both the reactive current I_Q detected in the CT 7 and a reference voltage V_{Href} of the high voltage side of the transformer 2.

9 indicates a subtracting unit for subtracting the output terminal voltage V_G detected in the PT 6 from the reference voltage V_{Gref} set in the voltage setting device 8 to obtain a subtraction value and outputting a difference signal indicating the subtraction value. 10 indicates an automatic voltage regulating device (hereinafter, called AVR) for controlling a commutation timing of an exciter 11 by using

the difference signal output from the subtracting unit 9 as an input condition for a transfer function. 11 indicates the exciter for supplying a field current to a field winding 12 of the synchronous machine 1 according to an instruction of the AVR 10. 12 indicates the field winding of the synchronous machine 1.

Fig. 2 is a flow chart showing a conventional excitation control method.

Next, an operation will be described.

A voltage V_G of the output terminal of the synchronous machine 1 is detected in the PT 6 (step ST1), and a reactive current I_Q output from the synchronous machine 1 is detected in the CT 7 and the PT 6 (step ST2).

When the reactive current I_Q is detected in the CT 7, a reference voltage V_{Gref} of the output terminal of the synchronous machine 1 is set in the voltage setting device 8 according to both the reactive current I_Q and a reference voltage V_{Href} of the high voltage side of the transformer 2 (step ST3).

Hereinafter, a setting method of the reference voltage V_{Gref} is described.

A relation between the voltage V_G of the output terminal of the synchronous machine 1 and a voltage V_H of the high voltage side of the transformer 2 is expressed according to an equation (1).

$$V_G = V_H + X_t \times I_Q \qquad (1)$$

Here, the symbol X_t in the equation (1) denotes a reactance of the transformer 2.

Also, as shown in Fig. 3, in cases where a plurality of synchronous machines 1 are connected to a power transmission system, reactance of each synchronous machine 1 with another synchronous machine 1 is equal to almost zero by applying the equation (1) as a relation between the reference voltage V_{Gref} and the reference voltage V_{Href}, a cross

current flows from one synchronous machine 1 to another synchronous machine 1 due to both a voltage difference of the output terminal voltages V_G and a response difference in each synchronous machine 1 with another synchronous machine 1, and each synchronous machine 1 has an excessive load. To suppress the generation of the cross current, as is expressed according to an equation (2), a reactance X_{DR} corresponding to the suppression of the cross current is subtracted from the reactance X_t of the transformer 2. Here, the reactance X_{DR} corresponding to the suppression of the cross current is set to a value equal to several % of the reactance X_t of the transformer 2, and the value of the reactance X_{DR} is empirically set.

$$V_{Gref} = V_{Href} + (X_t - X_{DR}) \times I_Q \qquad (2)$$

Therefore, the reference voltage V_{Gref} of the output terminal of the synchronous machine 1 is calculated in the voltage setting device 8 by substituting the reactive current I_Q output from the synchronous machine 1 and the reference voltage V_{Href} of the high voltage side of the transformer 2 into the equation (2).

When the reference voltage V_{Gref} of the output terminal of the synchronous machine 1 is set in the voltage setting device 8, the voltage V_G of the output terminal of the synchronous machine 1 detected in the PT 6 is subtracted in the subtracting unit 9 from the reference voltage V_{Gref} set in the voltage setting device 8 to obtain a subtraction value, and a difference signal indicating the subtraction value is output (step ST4).

When the difference signal is output from the subtracting unit 9, a timing signal for controlling a commutation timing of the exciter 11 is produced in the AVR 10, for example, by using the difference signal as an input condition for a following transfer function (step ST5).

$$\text{Transfer Function} = K \times (1 + T_{LD} \times s)/(1 + T_{LG} \times s) \qquad (3)$$

Here, the symbol K denotes a gain constant, the symbols T_{LD} and T_{LG} denote time constants, and the symbol s denotes a Laplace operator.

When the timing signal output from the AVR 10 is received in the exciter 11, a field current is supplied to the field winding 12 of the synchronous machine 1 according to the timing signal (step ST6). Here, when the difference signal output from the subtracting unit 9 is equal to a positive value, the field current supplied to the field winding 12 is increased, and the voltage V_G of the output terminal of the synchronous machine 1 is heightened. In contrast, when the difference signal output from the subtracting unit 9 is equal to a negative value, the field current supplied to the field winding 12 is decreased, and the voltage V_G of the output terminal of the synchronous machine 1 is lowered.

Therefore, the voltage V_G of the output terminal of the synchronous machine 1 is controlled so as to agree with the reference voltage V_{Gref}. Also, when the reactive current I_Q output from the synchronous machine 1 is equal to zero, the voltage V_H of the high voltage side of the transformer 2 is controlled so as to agree with the reference voltage V_{Href}.

$$V_G = V_{Href} + (X_t - X_{DR}) \times I_Q \qquad (4)$$

$$V_H = V_{Href} - X_{DR} \times I_Q \qquad (5)$$

Therefore, because the voltage of the power transmission bus line 5 is maintained to a constant value, even though a failure occurs, for example, in the power transmission line 4, the lowering of the voltage in the whole power transmission system can be lessened.

Because the conventional excitation control device has the above-described configuration, even though a failure occurs in the power transmission line 4, the lowering of the voltage in the whole power transmission system can be lessened. However, because no means for quickening the attenuation of an electric power fluctuation of

power transmission system occurring due to a failure of the power transmission system is arranged in the conventional excitation control device, a problem has arisen that it is required to additionally arrange a power system stabilization control device (PSS) for the purpose of quickening the attenuation of an electric power fluctuation.

The present invention is provided to solve the above-described problem, and the object of the present invention is to provide an excitation control device and an excitation control method in which the attenuation of an electric power fluctuation is quickened while controlling a voltage of the high voltage side of a transformer to a constant value.

DISCLOSURE OF THE INVENTION

An excitation control device of the present invention comprises a voltage setting means for setting a reference voltage of an output terminal of a synchronous machine according to a reactive current detected by a reactive current detecting means, a reference voltage of an output side of a transformer and a function of phase compensation used to quicken the attenuation of an electric power fluctuation.

Therefore, a voltage on the output side of the transformer can be set to a constant value, and the attenuation of the electric power fluctuation can be quickened.

In the excitation control device of the present invention, the reference voltage of the output terminal of the synchronous machine is set by the voltage setting means by considering the voltage of the output terminal of the synchronous machine detected by the voltage detecting means.

Therefore, the attenuation of the electric power fluctuation can be adjusted to a desired speed.

An excitation control method of the present invention comprises the step of setting a reference voltage of an output terminal of a synchronous machine according to a reactive current output from the synchronous machine, a reference voltage of an output side of a transformer and a function of phase compensation used to quicken the attenuation of an electric power fluctuation.

Therefore, a voltage on the output side of the transformer can be set to a constant value, and the attenuation of the electric power fluctuation can be quickened.

In the excitation control method of the present invention, the reference voltage of the output terminal of the synchronous machine is set by considering the voltage of the output terminal of the synchronous machine.

Therefore, the attenuation of the electric power fluctuation can be adjusted to a desired speed.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is constitutional view of a conventional excitation control device.

Fig. 2 is a flow chart showing a conventional excitation control method.

Fig. 3 is a system view showing an infinite bus line model.

Fig. 4 is constitutional view of an excitation control device according to a first embodiment of the present invention.

Fig. 5 is a flow chart showing an excitation control method according to the first embodiment of the present invention.

Fig. 6 is an explanatory view showing an internal configuration of a voltage setting device with electric power system stabilization function.

Fig. 7 is constitutional view of an excitation control device

according to a second embodiment of the present invention.

Fig. 8 is a flow chart showing an excitation control method according to the second embodiment of the present invention.

Fig. 9 is an explanatory view showing an internal configuration of a voltage setting device with electric power system stabilization function.

BEST MODE FOR CARRYING OUT THE INVENTION

Hereinafter, the best mode for carrying out the present invention will now be described with reference to the accompanying drawings to explain the present invention in more detail.

EMBODIMENT 1

Fig. 4 is constitutional view of an excitation control device according to a first embodiment of the present invention. In Fig. 4, 21 indicates a synchronous machine. 22 indicates a transformer. 23 indicates a circuit breaker. 24 indicates a power transmission line. 25 indicates a power transmission bus line of a power plant. 26 indicates a PT (or a voltage detecting means), denoting a potential transformer, for detecting a voltage V_G of an output terminal of the synchronous machine 21. 27 indicates a CT (or a reactive current detecting means), denoting a current transformer, for detecting a reactive current I_Q output from the synchronous machine 21. 28 indicates a voltage setting device with electric power system stabilization function (or a voltage setting means) for setting a reference voltage V_{Gref} of the output terminal of the synchronous machine 21 according to the reactive current I_Q detected in the CT 27, a reference voltage V_{Href} of the high voltage side of the transformer 22 and a transfer function $F_{H1}(s)$ of phase compensation used to quicken the attenuation of an electric power fluctuation of a power transmission system.

29 indicates a subtracting unit for subtracting the output terminal voltage V_G detected in the PT 26 from the reference voltage V_{Gref} set in the voltage setting device with electric power system stabilization function 28 to produce a subtraction value and outputting a difference signal indicating the subtraction value. 30 indicates an AVR, denoting an automatic voltage regulating device, for controlling a commutation timing of an exciter 31 by using the difference signal output from the subtracting unit 29 as an input condition for a transfer function of commutation timing. 31 indicates the exciter for supplying a field current to a field winding 32 of the synchronous machine 21 according to an instruction of the AVR 30. 32 indicates the field winding of the synchronous machine 21. Here, control means comprises the subtracting unit 29, the AVR 30 and the exciter 31.

Fig. 5 is a flow chart showing an excitation control method according to a first embodiment of the present invention, and Fig. 6 is an explanatory view showing an internal configuration of the voltage setting device with electric power system stabilization function 28.

Next an operation will be described below.

A voltage V_G of the output terminal of the synchronous machine 21 is detected in the PT 26 (step ST11), and a reactive current I_Q output from the synchronous machine 21 is detected in the CT 27 (step ST12).

When the reactive current I_Q is detected in the CT 27, a reference voltage V_{Gref} of the output terminal of the synchronous machine 21 is set in the voltage setting device with electric power system stabilization function 28 according to the reactive current I_Q, a reference voltage V_{Href} of the high voltage side of the transformer 22 and a transfer function $F_{H1}(s)$ of phase compensation used to quicken the attenuation of an electric power fluctuation (step ST13). In detail, the reference voltage V_{Gref} of the output terminal of the synchronous machine 21 is calculated by substituting the reactive current I_Q, the

reference voltage V_{Href} and the transfer function $F_{H1}(s)$ into the equation (6) (refer to Fig. 6).

$$V_{Gref} = V_{Href} + F_{H1}(s) \times (X_t - X_{DR}) \times I_Q \quad (6)$$

Here, the symbol X_t in the equation (6) denotes a reactance of the transformer 22, and the symbol X_{DR} denotes a reactance corresponding to the suppression of a cross current flowing in cases where a plurality of synchronous machines 21 are connected to a power transmission line. Also, $F_{H1}(s)$ denotes a transfer function in a phase compensation circuit in which a signal indicating a timing appropriate to quicken the attenuation of an electric power fluctuation is produced. For example, $F_{H1}(s)$ is set to a transfer function expressed according to an equation (7).

$$F_{H1}(s) = a_{1n} \times s^n + a_{1(n-1)} \times s^{n-1} + --- + a_{11} \times s + a_{10} \quad (7)$$

wherein the symbol s denotes a Laplace operator, and the symbols a denote constant values respectively.

Here, to make a voltage V_H of the high voltage side of the transformer 22 agree with the reference voltage V_{Href} in a normal operation, it is required to set each constant a of the equation (7) so as to set a gain of $F_{H1}(s)$ to 1 in the normal operation.

Thereafter, when the reference voltage V_{Gref} of the output terminal of the synchronous machine 21 is set in the voltage setting device with electric power system stabilization function 28, the voltage V_G of the output terminal of the synchronous machine 21 detected in the PT 26 is subtracted in the subtracting unit 29 from the reference voltage V_{Gref} set in the voltage setting device with electric power system stabilization function 28 to obtain a subtraction value, and a difference signal indicating the subtraction value is output (step ST14).

Thereafter, a timing signal for controlling a commutation timing of the exciter 31 is produced in the AVR 30 when the difference signal

output from the subtracting unit 29 is received as an input signal (step ST15).

Thereafter, when the timing signal output from the AVR 30 is received in the exciter 31, a field current is supplied from the exciter 31 to the field winding 32 of the synchronous machine 21 according to the timing signal (step ST16).

Here, when the difference signal output from the subtracting unit 29 is equal to a positive value, the field current supplied to the field winding 32 is increased, and the voltage V_G of the output terminal of the synchronous machine 21 is heightened. In contrast, when the difference signal output from the subtracting unit 29 is equal to a negative value, the field current supplied to the field winding 32 is decreased, and the voltage V_G of the output terminal of the synchronous machine 21 is lowered.

Therefore, the voltage V_G of the output terminal of the synchronous machine 21 is controlled so as to agree with the reference voltage V_{Gref}.

Also, the voltage V_G of the output terminal of the synchronous machine 21 has relation to the voltage V_H of the high voltage side of the transformer 22 according to an equation (8). Therefore, the voltage V_G of the output terminal of the synchronous machine 21 and the voltage V_H of the high voltage side of the transformer 22 are expressed according to equations (9) and (10) respectively by using the reference voltage V_{Href} of the high voltage side of the transformer 22.

$$V_H = V_G - X_t \times I_Q \qquad (8)$$

$$V_G = V_{Href} + (X_t - X_{DR}) \times I_Q \qquad (9)$$

$$V_H = V_{Href} - X_{DR} \times I_Q \qquad (10)$$

Therefore, when the reactive current I_Q output from the synchronous machine 21 is equal to zero, the voltage V_H of the high voltage side of the transformer 22 can be controlled so as to agree with the

reference voltage V_{Href}.

As is described above, in the first embodiment, the reference voltage V_{Gref} of the output terminal of the synchronous machine 21 is set according to the reactive current I_Q output from the synchronous machine 21, the reference voltage V_{Href} of the high voltage side of the transformer 22 and the transfer function $F_{H1}(s)$ of phase compensation used to quicken the attenuation of an electric power fluctuation. Therefore, the voltage V_H of the high voltage side of the transformer 22 can be controlled to a constant value. As a result, even though a failure occurs in the power transmission system or a load on the power transmission system is rapidly increased, the voltage V_H of the high voltage side of the transformer 22 can be stabilized. Also, because the attenuation of an electric power fluctuation can be quickened, the steady-state stability in an electric power system can be heightened.

EMBODIMENT 2

Fig. 7 is constitutional view of an excitation control device according to a second embodiment of the present invention. The constituent elements, which are the same as those shown in Fig. 4, are indicated by the same reference numerals as those of the constituent elements shown in Fig. 4, and additional description of those constituent elements is omitted.

33 indicates a voltage setting device with electric power system stabilization function (or a voltage setting means) for setting a reference voltage V_{Gref} of the output terminal of the synchronous machine 21 according to a reactive current I_Q detected in the CT 27, an output terminal voltage V_G detected in the PT 26, a reference voltage V_{Href} of the high voltage side of the transformer 22 and a transfer function $F_{H2}(s)$ of phase compensation used to quicken the attenuation

of an electric power fluctuation.

Fig. 8 is a flow chart showing an excitation control method according to the second embodiment of the present invention, Fig. 9 is an explanatory view showing an internal configuration of the voltage setting device with electric power system stabilization function 33.

Next an operation will be described below.

In the first embodiment, the reference voltage V_{Gref} of the output terminal of the synchronous machine 21 is set according to the reactive current I_Q output from the synchronous machine 21, the reference voltage V_{Href} of the high voltage side of the transformer 22 and the transfer function $F_{H1}(s)$ of phase compensation used to quicken the attenuation of an electric power fluctuation. However, it is preferred that a reference voltage V_{Gref} of the output terminal of the synchronous machine 21 is set by considering an output terminal voltage V_G detected in the PT 26.

In detail, as shown in Fig. 9, a reference voltage V_{Gref} of the output terminal of the synchronous machine 21 is set in the voltage setting device with electric power system stabilization function 33 according to a reactive current I_Q detected in the CT 27, an output terminal voltage V_G detected in the PT 26, a reference voltage V_{Href} of the high voltage side of the transformer 22 and a transfer function $F_{H2}(s)$ of phase compensation used to quicken the attenuation of an electric power fluctuation (step ST17).

$$V_{Gref} = V_{Href} + (X_t - X_{DR}) \times I_Q + \{V_{Href} + (X_t - X_{DR}) \times I_Q - V_G\} \times F_{H2}(s) \qquad (11)$$

Here, the symbol X_t in the equation (11) denotes a reactance of the transformer 22, and the symbol X_{DR} denotes a reactance corresponding to the suppression of a cross current flowing in cases where a plurality of synchronous machines 21 are connected to a power transmission line. Also, $F_{H2}(s)$ denotes a transfer function in a phase compensation circuit

in which a signal indicating a timing appropriate to quicken the attenuation of an electric power fluctuation is produced. For example, $F_{H2}(s)$ is set to a transfer function expressed according to an equation (12).

$$F_{H2}(s) = a_{2n} \times s^{n} + a_{2(n-1)} \times s^{n-1} + --- + a_{21} \times s + a_{20} \qquad (12)$$

wherein the symbol s denotes a Laplace operator, and the symbols a denote constant values respectively.

As is described above, in cases where the reference voltage V_{Gref} of the output terminal of the synchronous machine 21 is calculated, even though the transfer function $F_{H2}(s)$ is set to any value, the voltage V_H of the high voltage side of the transformer 22 agrees with the reference voltage V_{Href} in a normal operation (because $V_{Href} + (X_t - X_{DR}) \times I_Q - V_G = 0$ is satisfied in the normal operation). Therefore, the excitation control device of the second embodiment differs from that of the first embodiment in that it is not required to set a gain of $F_{H2}(s)$ to 1 in the normal operation, and the attenuation of an electric power fluctuation can be adjusted to a desired speed.

INDUSTRIAL APPLICABILITY

As is described above, in cases where an exciting system of a synchronous machine is controlled, the excitation control device and the excitation control method according to the present invention is appropriate to perform the stabilization of voltage in an electric power system and the improvement of steady-state stability in the electric power system.